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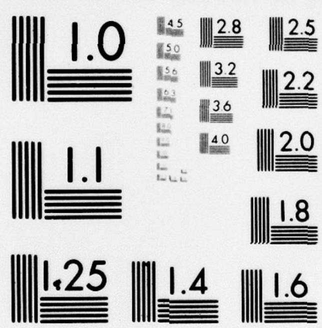

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DAYTIME VISUAL ACUITY OF OBSERVERS THROUGH A WINDOW WITH AND WITHOUT BINOCULARS

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JULY 1979

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AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICES

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Aerospace Medical Research Laboratory

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Visual acuity with and without hand-held M-19 7x50 binoculars was tested inside and outside of the cab of a Master Surveillance Control Facility (MSCF) Tower. High, medium and low contrast 3-bar resolution test charts were used at a 400-foot distance. Except for low contrast bar patterns, where loss was not large, unaided eye visual acuity was not impaired by cab windows.

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20. Abstract

With binoculars there was a statistically significant, though not large, window-caused loss of visual acuity for all contrasts. Even so, binocular visual acuity for high, medium and low contrast patterns was 5.6, 5.5, and 4.8 times, respectively, better than unaided eye acuity. Recommendations for the MSCF, based on this study, were made. A section of the report examines visual considerations in fence surveillance.

PREFACE

This report was prepared in the Human Engineering Division of the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. The work was performed in support of the Base and Installation Security System (BISS) Special Project Office, Electronic Systems Division, Hanscom Air Force Base, MA. It was done under Project 7184, "Man-Machine Integration Technology," and Task 718412, "Human Engineering Application to Systems Design, Test and Evaluation." Thanks are due to Mrs. Betty F. Reid and to Mrs. Dorothy M. Chouinard for their help in preparing the manuscript.

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INTRODUCTION

The surveillance of fences and ground areas from a position within an elevated glass enclosed structure can pose visual problems for observers. This is particularly true when binoculars, telescopes or other magnifying viewing devices are used. Optical quality windows are far too expensive to use for the large windows of surveillance structures. Windows that are actually used, even of good quality for unaided eye use, are not optically perfect, even when new. Glass surfaces are not optically flat, inside and outside surfaces are not perfectly parallel, and light is scattered by surface reflections, imperfections and the glass molecules themselves.

After only a very little use, surfaces acquire fingerprints and a thin coating of dust, oils and aerosols. In addition, surfaces quickly acquire a myriad of minute surface scratches and imperfections. The minute scratches can become glaringly obvious, though normally invisible, when looking through the glass in the general direction of the sun. Hard antireflection coatings are damaged by contact with hard objects, flying airborne dust, and by cleaning. All imperfections and unwanted deposits of oils, etc., increase light scattering. The scattered light, even when not noticeable directly, makes it difficult to see the small details of objects, particularly low contrast objects. Some vision loss occurs even when the window is new and appears, upon casual inspection, to be clean and in good condition. Binoculars or other magnifying devices, by enlarging distortions, can present a somewhat blurred view to the observer.

STATEMENT OF THE PROBLEM

The windows in the MSCF tower cause some loss of visual acuity. How much vision loss is to be expected, especially when using binoculars, is unknown. Loss could be negligible or it could be large. If it should turn out to be large, this should be known. In addition, much thicker "bullet-proof" windows will eventually be installed. These thicker windows will cause considerably more vision loss than that attributable to the current window.

The problem, then, is to test the current window and to also "pave the way" for tests of the new windows when they become available.

APPROACH AND EQUIPMENT

Visual acuity with and without hand-held binoculars, both when looking through the tower cab windows and when standing outside on the elevated platform, was measured. Observers were presented with a series of 3-bar resolution test patterns. A "bar" is a stripe or rectangle. An example of a test pattern is shown in figure 1. Note that, in this standard US Air Force pattern, the bars are five times as long as they are wide and spaces between bars are equal to the width of a bar. Instructions to observers were handed to them on a typewritten sheet, which is given in the Appendix. The observer's task was to select the smallest pattern that he could "resolve." A pattern was resolved when both the vertical and horizontal bars could be counted, i.e., seen as three in number, even if the pattern was seen as blurred. Figure 2 shows how the distance between the bar centers is used to calculate resolution or visual acuity in minutes of arc.

The charts with the test patterns were fastened to a stand on the ground at a slant range of 400 feet from the observer. There were three sets of targets: a high contrast set, a medium contrast set and a low contrast set. The bar pattern (or patterns of stripes) was white. The high, medium and low contrast test charts had, respectively, black, dark gray and light gray backgrounds. In this report contrast is defined by the formula: contrast = (bar reflectivity-background reflectivity)/(background reflectivity). By this definition, contrast can range from 0 to 1. The three sets of charts used in this study had contrasts of .91, .59, and .34. By the

sometimes-used definition of (light-dark) (100)/(dark), the contrasts were 1070, 144, and 52 percent, respectively. The charts were constructed to cover a range of visual acuity or resolution from 1/8 minute of arc to 2.5 minutes of arc at a slant range of 400 feet. Table 1 gives the dimensions of the test patterns.

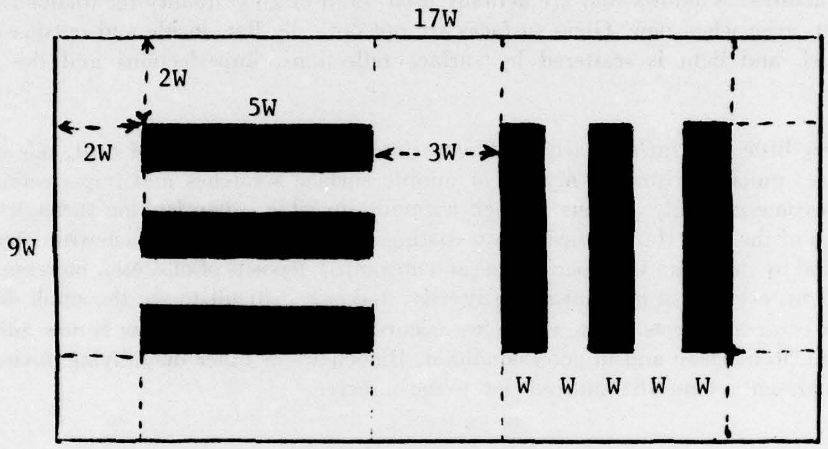
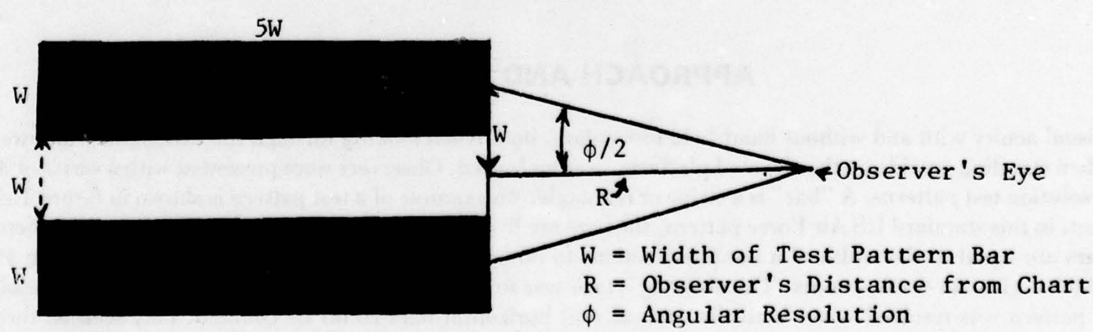


Figure 1. Resolution Test Target Configuration. The dashed lines do not apear on test charts.



$\tan(\phi/2) = (\phi/2)$ in Radians $= (\phi/2)(57.296 \times 60) = W/R = \phi/6875$.
Hence, ϕ in minutes of arc $= 6875\ W/R$. Note that optical scientists use the angle subtended at the eye by bar centers, 2W on the chart. Vision researchers use the width subtended by a bar, W, and regard $\phi/2$ as the angular resolution.

Figure 2. Angular Relationships of Test Target Resolution.

The testing was done with the test charts facing the sun and the observer facing the charts, hence facing away from the sun. The tower window through which observations took place was thus not illuminated by direct sunlight. Had observations been made facing the sun, scattered light from the sunlight impinging upon the window would undoubtedly have been a serious impediment to vision due to contrast loss and glare. This must be kept in mind. Data were not collected at low levels of illumination, such as are present along illuminated fence lines at night. How well one could observe through the windows at night was not measured. It may be inferred from optical and vision theory that, if little loss of acuity occurs in daylight, vision under low levels of illumination would also not be appreciably influenced by the windows. If the window absorbed much light, this of course, would not be the case.

The first four observers were tested with the visual acuity test charts in full sunlight and with the smoked Mylar® glare curtain or shade in place. The illumination on the test chart was 2,500 — 3,000 foot candles as measured with a Spectra Lumicon® Series II light meter. The last four observers were tested under completely overcast sky conditions with a measured chart illumination of 250 — 300 foot candles and with the glare curtain not in the line of vision. Tests on any one observer were completed within 20 — 30 minutes. Thus, illumination varied very little during tests on any one person.

Before the obtained data are examined, it is worthwhile to clarify a few points concerning visual acuity and its measurement. Resolution in the sense of separable acuity in optical and photographic science is stated in terms of the angle subtended by the centers of adjacent test bars or stripes. Bars are five times as long as wide and are separated by one bar width. Thus, from figure 2, it may be seen that the subtended distance between bar centers is 2W. Researchers in vision usually use the width of one test bar, W, or the space between bars, which is also W. Their angular measure subtends W, not 2W. They do this because the Snellen letters used in conventional eye test charts are composed of "strokes" that are one-fifth of the height of the letters. Thus, engineers and vision researchers, by their different criterion of angular subtense, differ by a factor of 2 in the angular resolution that they report. This difference in convention or definition is, to say the least, confusing and leads to misuse of research data. It may be remembered that the visual acuity of Table 1 uses the 2W, not W, subtense. Note the footnote to that table.

A second source of confusion is the fact that better visual acuity means smaller resolved angles: as acuity increases, arc minutes resolution decreases. For this reason, visual acuity is sometimes reported as the reciprocal of the resolved angle in minutes. While this may cause other problems, with acuity so defined, increase in visual ability is accompanied by increase in the numerical value of visual acuity.

RESULTS

The visual acuity or test pattern resolution obtained for all observers is listed in table 2. It will be recalled, from prior discussion, that the first four observers were tested with the test charts in sunlight, while the last four were tested with an overcast sky. Examination of the data reveals that, despite the 10:1 ratio of chart illumination, the groups performed equally well. Therefore, the data of all eight observers were combined.

Note, from table 2, that for the unaided eye, visual acuity from the tower for high and medium contrast targets is 1.5 to 2 minutes of arc, whether looking through the tower window or standing on the platform outside of the cab. The Snellen equivalent is ¾ — 1 minute of arc. Thus, for the high and medium contrast resolution test patterns, the window and no window results are almost identical: the window made no difference. However, for the low contrast target, the visual acuity is poorer: 1.75 versus 1.50 minutes of arc. The difference was large enough to be statistically significant ($t_7 = 4.49$, $P < .01$), i.e., was genuine. Thus, the window did result in a loss in unaided eye visual acuity for low contrast objects. This is to be expected. However, keep in mind that the loss was not large.

TABLE I

TEST CHART DIMENSIONS

VISUAL ACUITY ϕ	CHART NO.	TEST BARS+ WIDTH W*	LENGTH 5W	TEST CHARTS WIDTH = 17 W M.M.	Inches	HEIGHT = 9 W M.M.	Inches
3	1	53.2	266.0	904.2	35.6	478.7	18.8
2.5	2	44.3	221.6	753.5	29.7	398.9	15.7
2	3	35.5	177.3	602.8	23.7	319.1**	12.6
1.5	4	26.6	133.0	452.1	17.8	239.4	9.43
1	5	17.7	88.6	301.4	11.9	159.6	6.28
3/4	6	13.3	66.5	226.1	8.90	119.7	4.71
1/2	7	8.9	44.3	150.7	5.93	79.8	3.14
1/3	8	5.91	29.6	100.5	3.96	53.2	2.09
1/4	9	4.43	22.2	75.4	2.97	39.9	1.57
1/5	10	3.54	17.7	60.3	2.37	31.9	1.26
1/6	11	3.0	14.8	50.2	1.98	26.6	1.05
1/7	12	2.5	12.7	43.1	1.69	22.8	.897
1/8	13	2.2	11.1	37.7	1.48	19.9	.785

*W = 17.73 $\times \phi$ m.m. at 400 feet slant range, where ϕ is visual acuity in minutes of arc.

+ Test bar dimensions are in millimeters

Note: To convert to Snellen-equivalent acuity, which is conventionally used in vision research, divide the visual acuity, ϕ, column values by 2.

TABLE 2

VISUAL ACUITY IN MINUTES OF ARC

(A) High Contrast

Observer	Foot-Candles	The Unaided Eye			7x50 M-19 Binoculars			Eye-Binoculars	
		A	B	Ratio	C	D	Ratio	Ratios	
		No Window	Window	B/A	No Window	Window	D/C	A/C	B/D
1	3,000	1.5	1.5	1.00	.20	.333	1.66	7.50	4.50
2	3,000	1.5	1.5	1.00	.25	.25	1.00	6.00	6.00
3	3,000	1.5	1.5	1.00	.25	.25	1.00	6.00	6.00
4	2,500	2.0	2.0	1.00	.333	.333	1.00	6.00	6.00
5	300	1.5	1.5	1.00	.20	.25	1.25	7.50	6.00
6	250	1.5	1.5	1.00	.25	.25	1.00	6.00	6.00
7	300	1.5	1.5	1.00	.333	.333	1.00	4.50	4.50
8	250	1.5	1.5	1.00	.20	.25	1.25	7.50	6.00
Sum		12.5	12.5	8.00	2.016	2.249	9.16	51.0	45.00
Mean		1.56	1.56	1.00	.252	.281	1.14	6.38	5.62
Mode*		1.5	1.5	1.00	.225	.25	1.00	6.00	6.00

(B) Medium Contrast

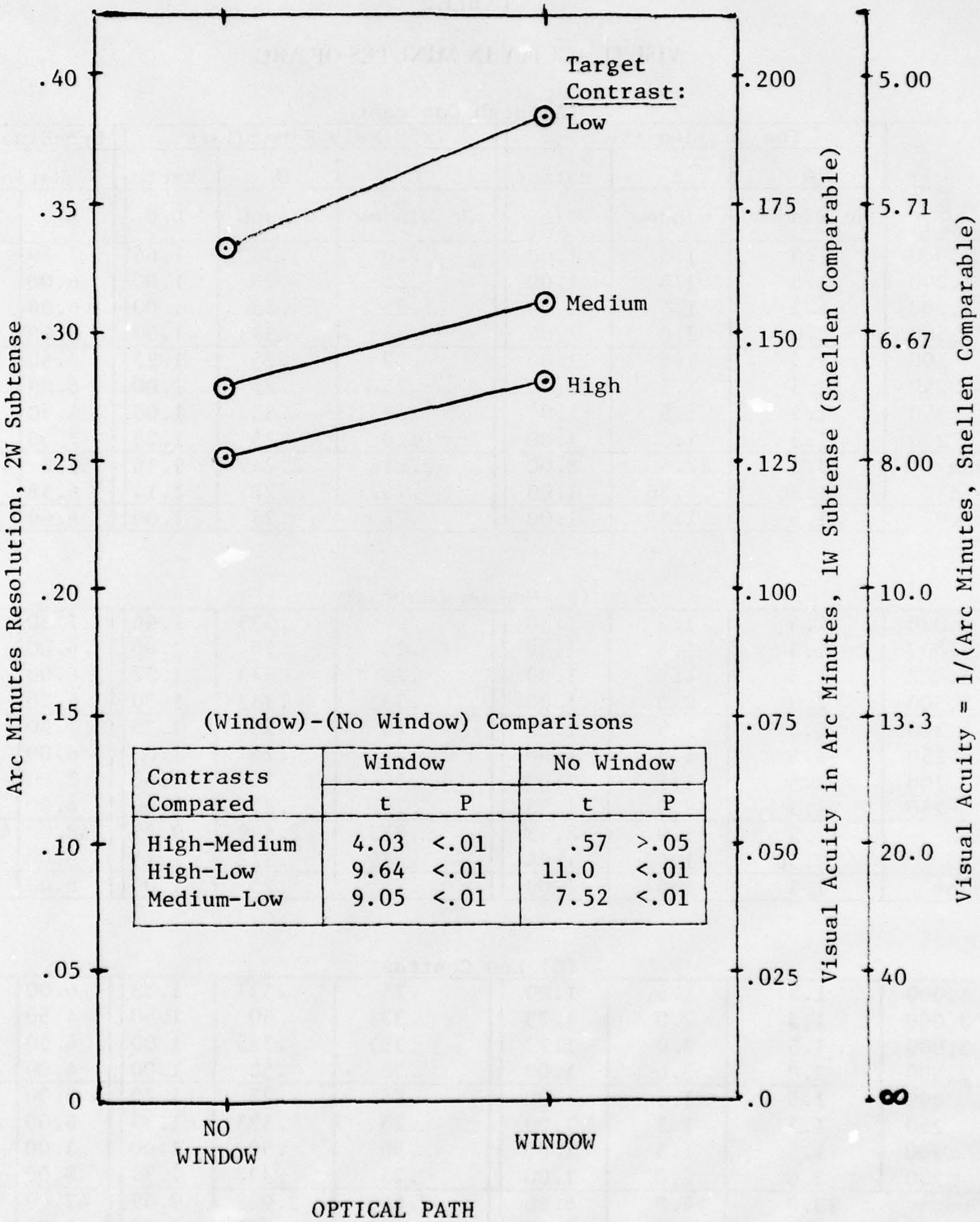
1	3,000	1.5	1.5	1.00	.20	.333	1.66	7.50	4.50
2	3,000	1.5	1.5	1.00	.25	.25	1.00	6.00	6.00
3	3,000	1.5	1.5	1.00	.25	.333	1.32	6.00	4.50
4	2,500	2.0	2.0	1.00	.333	.333	1.00	6.00	6.00
5	300	1.5	1.5	1.00	.20	.25	1.25	7.50	6.00
6	250	1.5	1.5	1.00	.25	.25	1.00	6.00	6.00
7	300	1.5	1.5	1.00	.50	.50	1.00	3.00	3.00
8	250	1.5	2.0	1.33	.25	.25	1.00	6.00	8.00
Sum		12.5	13.0	8.33	2.233	2.499	9.23	48.00	44.00
Mean		1.56	1.62	1.04	.279	.312	1.15	6.00	5.50
Mode*		1.5	1.5	1.00	.25	.25	1.00	6.00	6.00

(C) Low Contrast

1	3,000	1.5	1.5	1.00	.25	.333	1.33	6.00	4.50
2	3,000	1.5	2.0	1.33	.333	.50	1.50	4.50	4.00
3	3,000	1.5	2.0	1.33	.333	.333	1.00	4.50	6.00
4	2,500	2.0	2.0	1.00	.50	.50	1.00	4.00	4.00
5	300	1.5	1.5	1.00	.25	.25	1.00	6.00	6.00
6	250	1.5	1.5	1.00	.25	.333	1.33	6.00	4.50
7	300	1.5	1.5	1.00	.50	.50	1.00	3.00	3.00
8	250	2.0	2.0	1.00	.25	.333	1.33	8.00	6.00
Sum		13.0	14.0	8.66	2.666	3.082	9.49	42.00	38.00
Mean		1.62	1.75	1.08	.333	.385	1.19	5.25	4.75
Mode*		1.5	1.75	1.00	.25	.333	1.00	6.00	5.25

Note: Acuity values are based on distances between bar centers, 2 W. To obtain Snellen-equivalent, or W based acuity, multiply the tabled values by .50.

*The mode is the most frequent value. When two values are equally frequent, the average of the two is given in the table.



Contrasts Compared	Window t	Window P	No Window t	No Window P
High-Medium	4.03	<.01	.57	>.05
High-Low	9.64	<.01	11.0	<.01
Medium-Low	9.05	<.01	7.52	<.01

Figure 3. Comparison of Visual Acuity Under Window and No Window Conditions with M-19 7x50 Binoculars.

The effect of the tower window on visual acuity with binoculars is revealed by a comparison of the "window" and "no window" (or C and D) columns. This is facilitated by examination of figure 3 which plots acuity against optical path for the binoculars. Note the two vertical scales on the left side ot the figure. It may be noted from the table and from the figure that, for all three acuity test target contrasts, the average visual acuity is poorer (a larger number) when looking through the tower window. This observed difference in means or averages is verified by statistical tests. For the high, medium and low target contrasts, the "t" values are 7.03, 6.90 and 6.68, respectively. Each has a corresponding probability of less than .01, i.e., all are statistically significant. At every level of target contrast, the window reduces visual acuity with binoculars. This is what one would expect.

Optical theory and the data in vision research publications indicate that ability to discern fine details of target objects worsens as target contrast is reduced. In the present study this notion may be examined by study of the average or mean values listed in table 2 and plotted in figure 3. For the "no window" data it is clear that visual acuity worsens in going from high to medium to low contrast patterns. The largest loss occurs in going from medium to low contrast patterns. Both of these observations may also be made concerning the data for the condition where there is no tower cab window in the optical path of the binoculars. These findings of vision loss with lower contrast test patterns are verified by the (window)-(no window) comparisons listed in the table that is given in figure 3. Five of the six "t" values are statistically significant at the .01 level of significance.Whether or not the tower cab window is in the optical path, decreasing target pattern contrast is accompanied by decreasing ability to discern fine details with binoculars.

While the cab window does cause poorer vision, as expected, the important point to keep in mind is that this loss in visual ability is not large. From the D/C ratio column of table 2, it may be noted, in the means or averages rows, that the means ratios are 1.14, 1.15 and 1.19, respectively, for the high, medium and low contrast resolution test patterns. The worst loss, which is at low contrast, is only 19%. This does not appear to be excessive. Any window that would be economically feasible would cause some loss. It is therefore judged that the current MSCF tower windows are not bad windows. They appear to be acceptable for use with binoculars.

It is of some interest to compare visual acuity with and without binoculars. The ratios of the acuities are listed in the A/C column for no window and the B/D column for looking through the tower window. Note that the means or averages vary from 4.75 (low contrast, window) to 6.38 (high contrast, no window). Most observers could discern 4.5 to 6 times smaller detail with the binoculars than with the unaided eye. Note that, except for the low contrast window condition, the mode (or most common value of the ratio) was 6.00 For many observers, visual acuity with hand-held 7x50 binoculars is about 6 times better than the visual acuity of the unaided eye.

Users of the present report are more likely to be vision researchers than optical scientists. In summarizing test findings, the Snellen eye test chart convention, W, will therefore be used. Keeping this in mind, the main findings of the present report may be summarized as follows:

1. For high and medium contrast objects, daytime resolution of the unaided eye through the cab window is about .75 minutes of arc. It is about .88 minutes of arc for the low contrast test charts.

2. Except for low contrast objects, the tower window did not adversely influence unaided eye visual acuity.

3. Most observers with hand-held 7x50 binoculars achieved .12 to .16 arc minute visual resolution through the tower cab windows for high and medium contrast objects. For low contrast objects, the values were .16 to .25 for most observers.

4. For all contrast levels there are statistically significant, though not large, loss of visual acuity with binoculars caused by the windows.

5. Window loss was largest for low contrast test charts, amounting to about 19% for binoculars. As target contrast decreased, so did ability to discern fine details with binoculars.

6. For high and medium contrast objects, binocular visual acuity through the window was 5.6 and 5.5 times better, respectively, than acuity of the unaided eye. It was 4.75 times better for low contrast objects.

DISCUSSION AND RECOMMENDATIONS

The test data show that loss of visual acuity attributable to the MSCF tower window and smoked plastic glare curtain or shade was present for low contrast patterns for the unaided eye. Some loss, on the average, was present for all three contrast levels when hand-held 7x50 binoculars were used. It may be noted from the data table that some observers did not appear to incur acuity loss with the windows. This apparent lack of impairment was undoubtedly due to the differences between the "steps" in size from one test pattern to the next. Probably a larger series of test patterns with smaller jumps in size from one to the next would have revealed some loss of acuity for all tests made through the windows. Optical and vision theory say that windows would cause some, however slight, loss when looking through them. The present series of acuity test patterns are adequate to detect any appreciable loss in visual acuity.

The important point to keep in mind is that the vision loss due to the tower windows was small. This was found even though the windows had been on the tower for several months, so were not brand new. The authors maintain that the loss in visual acuity due to the current thin windows is acceptable. It would not be worthwhile to replace them with windows of better optical quality.

However, when new, much thicker windows are installed, they should be tested for their optical effects, particularly with binoculars, both in daylight and under low illumination levels. Loss of acuity is certain to be larger than with current thin windows, and could be much larger. Data on thick windows could aid in determining the maximum distance away from the observation tower that would be advisable for direct visual surveillance with the eye aided by binoculars.

VISUAL CONSIDERATIONS IN FENCE SURVEILLANCE

The present study examined the adequacy of current Base and Installation Security System (BISS) surveillance tower windows. They were found to cause some loss of visual ability, but the loss was small. It was concluded that: (1)the detection and recognition of intruders near fences is hampered very little by the optical quality of the current observation tower windows, and that (2) it would not be worthwhile to obtain windows with higher optical quality.

Granted that the current windows are optically acceptable, one wonders about the maximum distance from the tower that will still permit reliable detection and recognition of human intruders by an observer in the tower who uses hand-held binoculars. At distances which are too large for direct visual surveillance, closed circuit television or some other equipment would be used.

Ideally, one would arrive at a "one-number" answer to the basic question of maximum permissible distance for visual surveillance. Unfortunately, from the standpoint of those liking a simple one number answer, the situation is not simple. The numerical value for distance depends upon the specific value assigned to each one of a large number of variables. Clearly, the higher the required probability of detection and recognition required, the shorter the distance will be. Also, the smaller the size of the intruder, the shorter the permissable distance. It is known that the contrast of an intruder with the background against which he appears makes a very large difference in detection and recognition. This is illustrated by figure 4, a replot made for this paper from figure 5. It is unlikely that a value of contrast can be selected that will be acceptable to everyone concerned with the problem. However, it is clear that a value of zero contrast cannot be used. It is unlikely that

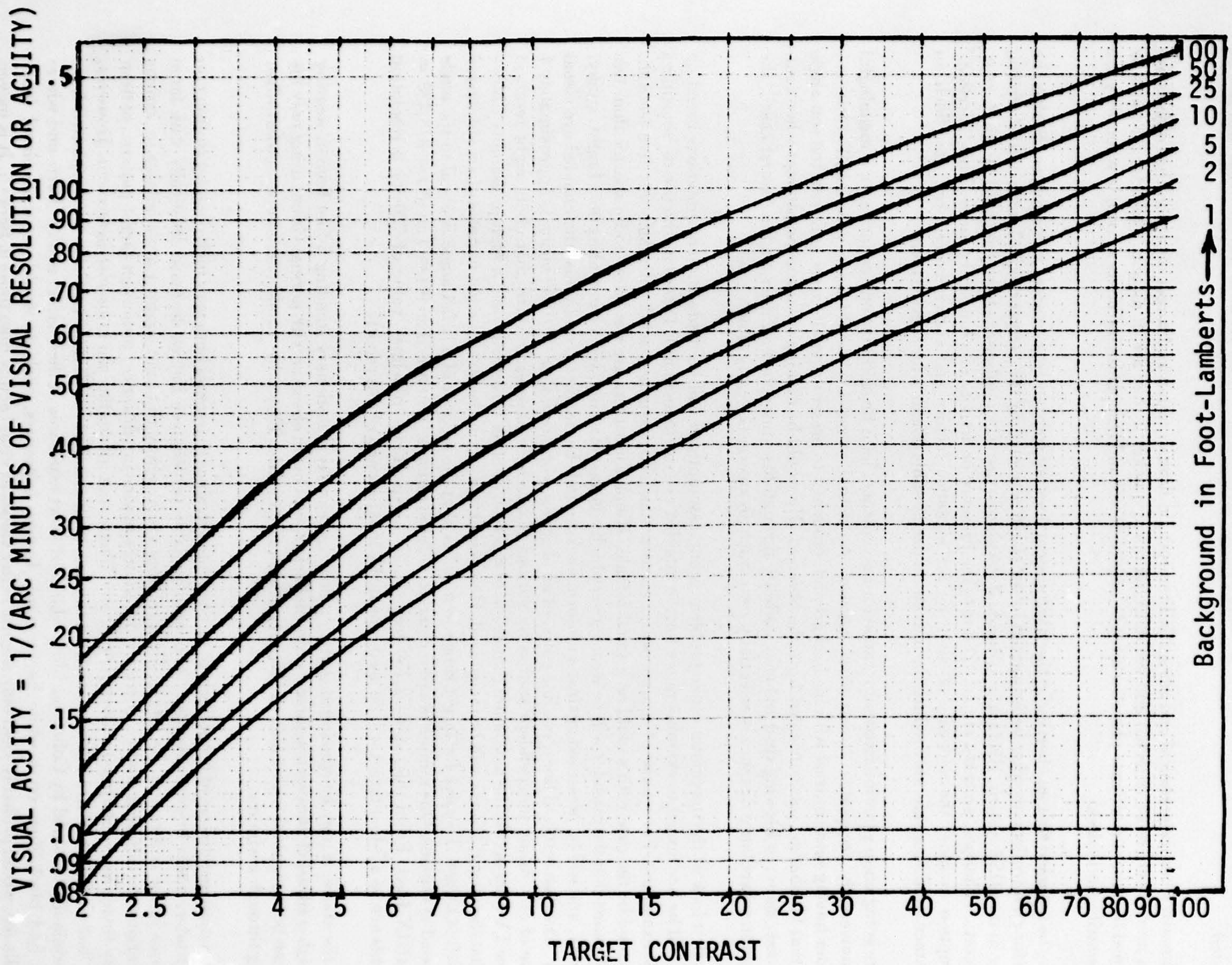


Figure 4. Visual acuity plotted against target contrast for various values of background luminance in foot-candles.

even a sophisticated professional intruder with intensive preparation will be wearing garments with a near zero contrast with the background. This may be possible when snow is on the ground, but this case will not be included.

It is known from the technical and scientific literature on human vision and target detection that objects are much more likely to be detected and are detected much quicker if they are in motion. However, it must be assumed that the surveillance observer must be able to detect and reacognize intruders as people when they are temporarily motionless.

It may be assumed that an observer in the BISS system does not constantly scan areas along fences. Rather, he looks for an intruder only after being alerted by an alarm activated by the "triggering" of some sort of sensing device in the BISS system. His task is to decide if the alarm was: (1) a nuisance alarm triggered by wind, rain, temperature changes, animals, etc., or (2) due to the presence or activity of a human intruder. This "alerting" assumption excludes the necessity of allowing for vigilance factors and search procedures, etc. Such an allowance would considerably reduce the maximum permissable distance for surveillance.

Before going on to examine maximum range for surveillance, let it be said that one cannot give a meaningful and universally acceptable "worst case" answer. An actual worst case would be a very small stationary intruder having zero contrast with his background, crouched to present a small target and with the sun angle such that his shadow was concealed from the observer. He would be making his intrusion attempt when rain, fog, haze, snow, or blowing dust reduced visibility through the atmosphere. Under such a "worst case", the maximum surveillance distance is essentially zero. Such an answer is clearly of no value.

For a first look at the maximum range problem, some assumptions will be made and computations based on them will be performed to examine range for the unaided eye (no binoculars). Later on, the use of binoculars will be examined. For a basis of comparison, i.e., as a standard, assume a small intruder, only five feet tall. This could be the case with a child or a small female. Human intruders are not likely to be shorter than five feet. Assume that the intruder will be wearing very high contrast clothing, will be intruding on a bright, sunny, clear day, and will be presented against a uniform background. Under these conditions, the unaided eye visual acuity, based on resolved lines, not line pairs, of an observer with normal or "20/20" vision is approximately 1 minute of arc. Many independent studies by various researchers have established that about eight resolved lines or TV lines across the maximum dimension of a person or other target will yield a high probability (.80 — .90) that the target, if seen, will be recognized. Here, eight resolution elements is eight minutes of arc subtended by a 5-foot target. To solve for target range, remember that the tangent of a small angle is equal to the angle expressed in radians. One minute of arc is equal to 1/3,438 radians. Whence, Tan (θ) = Tan (8') = 8/3,438 = (5 feet)/(X feet). From this, X = 2,150 feet = 720 Yards. This "baseline" value of 720 for 8 resolution elements across a 5-foot target will be used repeatedly in later parts of this report.

From the above, it may be concluded that on a bright, clear day a stationary standing 5-foot human wearing very high contrast clothes seen against a uniform background by an observer with normal vision, using only his eyes, can be recognized with a high probability at about 700 yards. This value would decrease somewhat when looking through a window.

The situation just discussed is not likely to be encountered, since it assumes both very high contrast clothing on the intruder, and a bright, clear day. Maximum reliable surveillance ranges decrease drastically with large decreases in the contrast of the target. Data relating visual acuity to target contrast are available in various publications. In different studies, there are differences in viewing distance, resolution target pattern, pattern polarity (black vs. white bars), viewing time, etc. Hence, not all studies are in precise agreement. However, some "ball park" estimates can be made from the data plotted in figure 5. These data have been replotted from data originally obtained by Cobb and Moss who used short exposures of their visual acuity charts and whose charts had black lines on a white background. Longer exposures, such as would occur in visual fence surveillance, would probably yield only slightly better values of visual acuity than those in figure 5. It is judged

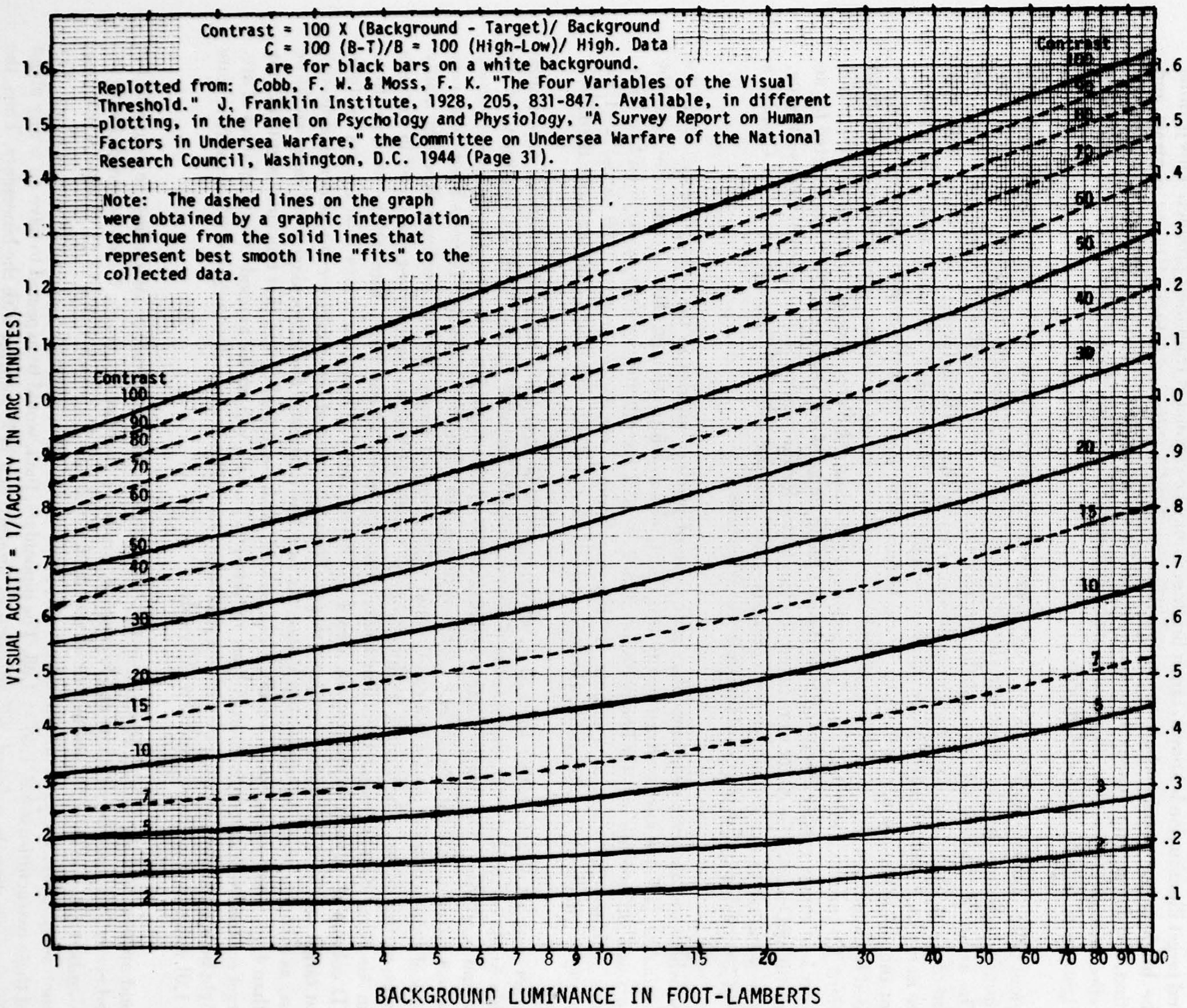


Figure 5. Visual acuity of the unaided eye at various contrast levels and background brightnesses. Multiply luminances in foot-lamberts by reflectivity to obtain approximate values of illumination in foot-candles.

that the data are adequate for comparison of visual acuity at different contrasts and brightnesses. The graph's horizontal axis is background brightness, rather than background illumination. Thus, the X axis is in foot-lamberts (brightness) rather than fott-candles (illumination). For surveillance purposes, target illumination is more convenient to use than the target brightness given in the figure. If target reflectance is known and target illumination is known, target brightness may be calculated from their product. This permits use of the brightness — acuity chart to obtain visual acuity for different values of target contrast and illumination. For discussion pusposes, let it be assumed, for the duration of this report, that an intruder has a diffuse reflectance of 20% and is illuminated with 10 foot-candles. This combination yields an equivalent target brightness of .20 x 10 = 2 foot-lamberts.

The 720-foot value obtained earlier was for a very high contrast target. Going far in the other direction for a second situation, assume that the 5-foot intruder has a contrast with his background of only 5%, a quite low value. The assumed .20 light reflection of the intruder times the 10 foot-candles of illumination gives the equivalent of about 2-foot-lamberts for entering the visual acuity chart. The indicated visual acuity, defined in the figure as the reciprocal of acuity in arc minutes, is about .21. This yields 1/.21, or about 4.8 arc minutes. Note that this is only about one fifth of the 1 arc minute value for "normal" human vision with brightly illuminated high contrast targets. The corresponding surveillance range for 4.8 arc minutes is obtained from the standard 720 yards at 1 minute. It is: (720 yards) x (1 arc minute/4.8 arc minutes), or 150 yards. Here, the unaided eye is adequate to only about 3/8ths of the maximum range of 400 yards that BISS has selected for an observer with binoculars. If account were taken of a loss factor for the window due to internal light scattering, which is very harmful to vision at very low contrasts, then even the 150 yard figure is too large. Clearly, a distance of 400 yards requires the use of binoculars or telescopes.

The case where the observer uses binoculars is the one of primary interest in the present study. With the well-illuminated 34% (or low) contrast acuity test chart, visual acuity through the tower window with the binoculars was .385 arc minutes for line pairs, or .385/2 = .192 arc minutes for lines rather than line pairs. Using this with the 720 yards at 1 minute yields a maximum surveillance range of (720 yards) x (1 arc minute/.192 arc minutes) = 3,750 yards. However, an intruder probably will have a contrast lower than 34%.

At a target contrast of 5%, rather than 34%, this range will be drastically reduced. A further appreciable reduction would occur in the calculated value if allowance could be made for the "contrast rendition" of the window and binoculars. The internal light scattering of the windows and binoculars used in the present study was not very harmful with the low (or 34%) contrast target, but would be expected to be more harmful at very low levels of target contrast. At 10 foot-candles and a 5% contrast target, the eye resolution from the acuity graph was, earlier, found to be about 4.8 minutes of arc. For the 34% (low) contrast test chart used in the tests at Eglin Air Force Base, (average binocular acuity)/(average acuity of eyes only), through the window, from the B/D column of Table 2 of this report, was 4.75. From Table 2, note that it was 5.50 for the medium contrast target and 5.62 for the high contrast target. Thus, the ratio of binocular-to-eye was decreasing with contrast, as is to be expected from optical theory. At very low contrasts, the (binocular)/(eye) ratio would be lower than 4.75. Thus, using the 4.75 ratio, it can be said, with some confidence, that binocular acuity at only 5% target contrast will be poorer than (4.8 arc minutes)/4.75, i.e., will not be as good as 1.01 minutes of arc, and might be appreciably worse. This yields a maximum surveillance range of less than (720 yards) (1 minute of arc/1.01 minutes of arc), i.e., less than 710 yards.

A second approach to the 5-foot, 10 foot-candle, 5% contrast situation involves comparing the acuity of the unaided eye at 34% contrast to acuity at 5% contrast. From the visual acuity graph, it may be noted, above the 2 foot-lambert value on the 5% contrast curve, that acuity is about .21, which yields 1/.21 = 4.8 arc minutes. At a contrast of 34%, the same graph indicates approximately .64, yielding 1/.64 = 1.56 arc minutes. The ratio of these two acuities is 4.8/1.56 = 3.08. The binoculars, then, would be expected to have an acuity about 3.08 times poorer than the value of .385 arc minutes obtained at a 34% contrast with the binoculars. Thus, the observer with the binoculars would have a visual acuity that would not be as good as (3.08) (.385) = 1.19 arc minutes. This yields a surveillance range of less than (720 yards for 1 minute of arc)/(1.19 arc minutes) = 605

TABLE 4

MAXIMUM INTRUDER RECOGNICITON RANGES+ WITH HAND-HELD BINOCULARS

(A) Under Good Illumination, Equivalent to About 500 Foot-Candles.

For 10% contrast, use ratio of eye alone at 34% contrast to that at 10%, both at 100 foot-lamberts on the acuity chart, and multiply by binocular acuity at 34% contrast to obtain acuity. Similarly for 5%. Since intruders are unlikely to have contrasts above 34%, the ranges for contrasts of 59% and 91% are not included.

Target Contrast	Binocular Acuity A, in arc minutes	Range in Yards = 720/A
34	.385	1900
10	(.385)(1.13/.66) = .659	<1100
5	(.385)(1.13/.44) = .989	< 730

(B) Under 10 Foot-Candles Illumination

Use binocular acuity from table (A) above. Multiply by ratio of acuity at 100 foot-lamberts on the acuity graph to acuity at 2 foot-lamberts on the graph, assuming a 20% reflection intruder illuminated by 10 foot-candles.

Target Contrast	Binocular Acuity B, in arc minutes	Range in Yards = 720/A
34	(.385)(1.13/.65) = .669	1100
10	<(.659)(.66/.35) = 1.24	< 580
5	<(.989)(.44/.23) = 1.89	< 380

+Assuming a 5-foot tall standing stationary intruder with the contrast indicated reflecting 20% of incident light. Range = (720 yards for 1 minute of arc)/(acuity in arc minutes).

yards. Keeping in mind that both methods overestimate range by an unknown amount, note that both the 710 yard and 605 yard overestimates are above 400 yards.

Table 4 has been prepared to permit rough approximations of recognition ranges at various contrasts. The (A) portion represents visual surveillance range with binoculars for a scene illumination of around 500 foot-candles. It may be noted, from table 2, that this is just above the 250-300 foot-candles of illumination that prevailed for the second four observers measured at Eglin Air Force Base. The Cobb and Moss data go out to only 100 foot-lamberts. With a 20% reflection target, this 100 corresponds to about 5 x 100 = 500 foot-candles of illumination. In full sunlight, vision is somewhat better, even though the small number of observers at Eglin and the size of the acuity steps of the charts used did not show this. The value in the (A) part of table 3 for 10% contrast uses binocular acuity at 34% contrast through the tower window and multiplies this by the ratio of acuities at 34% and 10% contrast, both at 100 foot-lamberts, to obtain binocular acuity at 10% contrast. Acuity at 5% contrast is calculated in a similar manner.

The acuity values in good illumination of part (A) of the table are converted to values at 10 foot-candles by multiplying by the ratio of unaided eye acuity at 100 foot-lamberts to acuity at 2 foot-lamberts. Both tables assume: (1) eight resolved lines across the targets length, (2) a 20% reflecting target that is (3) 5 feet tall, (4) standing and stationary, (5) presented against a uniform background, (6) in a small search area, and (7) is "looked for" by an observer alerted by an alarm.

The reader may, using table 2, the visual acuity graph of figure 5 and the procedures of the above paragraphs, calculate surveillance ranges for various values of resolved lines, reflectivity, ambient illumination, target size, etc. While the procedure is not difficult, keep in mind the approximate-only accuracy.

It is important for the reader to keep in mind the fact that the calculations in the present report used a criterion or measure of 8 lines resolution across the maximum dimension of the target. As mentioned earlier, many studies have found this value of 8 for resolution to be adequate. Larger numbers of rsolution elements covering targets have been found to yield only a slightly higher probability of recognition than that yielded by eight lines. If a larger value were to be used, the ranges would be reduced below those given in the computations. Thus, if 13 lines were used instead of 8 lines, the estimated maximum surveillance range would be reduced by a factor of 8/13. A second fact that should be kept in mind is that the chart giving visual acuity at various contrasts and luminances was derived from data collected with black bars on a white background. The acuity charts used in the present study had white bars. This is an additional reason for regarding the computational results as only approximate.

The maximum permissible or useful surveillance range is decreased when more resolution of target details is necessary, or when smaller or lower contrast targets must be recognized. The present paper examined values of target size, resolution and contrast that appear to be adequate for resolving the human intruder recognition range problem. From the calculations presented the authors conclude that an observer with hand-held binoculars can recognize stationary 5-foot targets at ranges of over 400 yards. Visual surveillance of clear areas near fences for human intruders is permissible at ranges of at least 400 yards.

APPENDIX I

INSTURCTIONS FOR OBSERVERS

Your observations will be used in evaluating how well an observer can see things from the MSCF tower. You will look at a series of test charts on the ground several hundred feet away from the tower. These charts are known as "Resolution" charts. They contain patterns in the form of strips or "Bars". A pattern consists of three vertical bars and three horizontal bars.

With the largest strips or bars, there is only one pattern to a chart. The chart with the next-to-smallest bars contains three patterns, and the chart with the smallest bars contains seven patterns. There are three versions or "Sets" of each chart. They differ only in the contrast of the bars with the rest of the chart. The light gray chart yields low contrast; the medium gray chart yields medium contrast, and the black chart yields high contrast.

Examine each chart as it is presented to see if you can count both the vertical and horizontal bars in every pattern on the chart. If you can *see* three vertical and three horizontal bars, *even if they look somewhat blurred*, on a chart, say: *"I can resolve all of them."* If you cannot resolve all of the patterns, select the pattern that you can just resolve and determine what number it is. To do this, *study* the attached sheet which shows what all of the charts look like. Note that for the 3-pattern chart the bar size decreases from left to right. However, for the 7-pattern chart, while the top row of three patterns decreases in size from left to right, *the bottom row of four patterns decreases in size from right to left*. During observations, you will be using the sheet with the pictures of the charts so that you do not have to memorize it. The numbers on the patterns on the instruction sheet do *not* appear on the actual charts. Chart "A" will not be used in the current series of observations: Chart "B" will have the coarsest pattern.

In some observations, you will use only your eyes, and in some, you will be using binoculars. When you use binoculars, you will be *assisted* in adjusting the separation of the eyepieces and focusing the binoculars. Focus will be adjusted while looking at the charts from the tower.

RESOLUTION CHARTS

There are four basic charts, each duplicated at three contrasts, for a total of 12 charts. Charts are labeled B, C, D, and E. The patterns of bars are numbered as shown below. Numbers do *not* appear on the charts! Each chart has only a *letter* designation. The figures below are *sketches* and are not drawn to scale.

Chart (B)

Only 1 pattern.

Chart (C)

Only 1 pattern.

Chart (D): Three patterns.

Size Decrease

Size Decrease

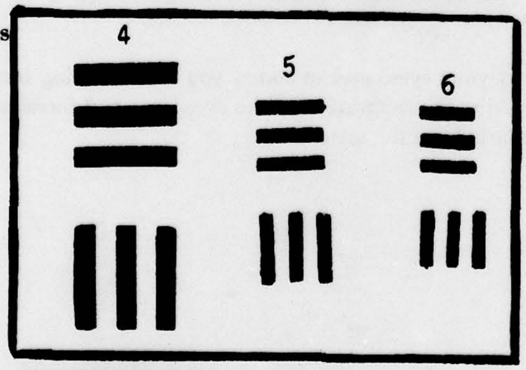


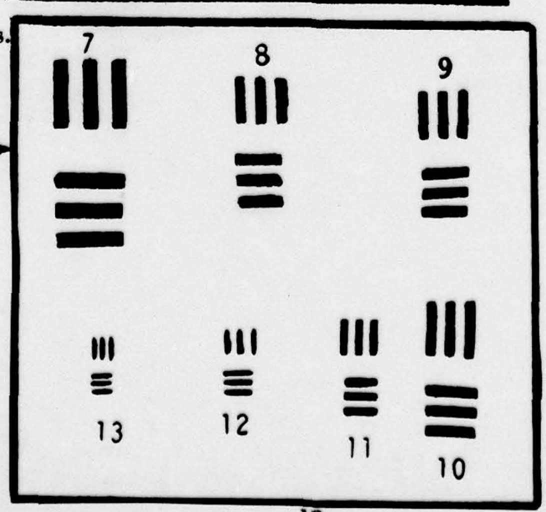
Chart (E): Seven patterns.

Top Row

Size Decrease:

Bottom Row

Size Decrease



APPENDIX II

CONTRAST OF TEST CHARTS

Samples of the material used in making the visual acuity test charts were measured, one at a time, in diffuse constant room lighting with a calibrated Pritechard Digital Photometer. Readings were as follows:

Sample of Material	Reading in Foot-Lamberts
Black	2.10
Dark Gray	10.1
Light Gray	16.19
White	24.6

Contrast was defined as: $C = \frac{\text{High-Low}}{\text{High}} = \frac{\text{Target-Background}}{\text{Target}}$

This yielded contrasts as follows:

High Contrast = (24.6-2.1)/24.6 = .91

Medium Contrast = (24.6-10.1)/24.6 = .59

Low Contrast = (24.6-16.19)/24.6 = .34

Expressed as a percentage, these would be 91, 59, and 54 respectively.

By a second definition: Contrast $= \frac{\text{High-Low}}{\text{Low}} \times 100 = \frac{\text{Target-Background}}{\text{Background}} \times 100$

High Contrast = (24.6-2.1)(100)/2.1 = 1070

Medium Contrast = (24.6-10.1)(100)/10.1 = 144

Low Contrast = (24.6-16.19)(100)/16.19 = 51.9

*U.S.Government Printing Office: 1979 — 657-002/158